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# A Self-Propelled Machine For Mass Collection of Insects

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Field collecting large numbers of live insects is common in insect studies. In a cooperative research program[2] entomologists designed a vacuum-operated mass collecting device that reduces labor and effectively collects a variety of insects.

Previously, entomologists used sweep nets to mass collect adult cereal leaf beetles, *Oulema melanopus* (L.), and other insects. In addition to the cereal leaf beetles, the machine collected such other insects as parasitized adult alfalfa weevil, *Hyper postica* (Gyllenhal), and tarnished plant bug, *Lygus lineolaris* (Palisot de Beauvois).

The machine was designed to meet the following specifications: (a) low cost because of intermittant use; (b) easy to transport wherever insects are abundant; (c) small enough to minimize crop damage because of frequent use on private land; (d) adaptable in a variety of collecting situations (stubble, headed grains, and heavy grasses); (e) easy to operate to reduce labor; (f) to operate trouble-free with standard parts; and (g) to equal the sweep net in effectiveness. A mass collecting machine meeting these specifications is described in the design section.

Small and easily transported, this mass collecting machine can be used under conditions that would hamper the use of sweep nets. This machine also proved easily adaptable for use in a variety of entomological studies.

Because literature on mass collecting insect devices is scarce, literature on insect sampling and control equipment was used in designing the present machine. In 1876, Riley and associates (*6*)[3] presented a number of mechanical devices for destroying grasshoppers. Whether the machines were man- or horse-powered, some of the basic designs were sound for mass collecting insects.

In 1959 Dietrick and associates (3) developed a portable gas-powered vacuum that drew the insects directly into a sampling net. This device was later adapted with a small gas motor that could be carried on a man's back (2). Available commercially, this latter model is widely used for sampling insects[4] (9). A wheeled cart adaptation of this device was developed by Schroder (8).

The first use of a portable mass collecting vacuum was reported by van den Bosch and associates (*11*) for mass collecting parasites of the spotted alfalfa aphid, *Therioaphis maculata* (Bucton). This portable fan was connected by ducts to a scoop on the front of a truck. Stern and others (*10*) mounted the same type of device on a high clearance tractor for mass collecting *Lygus hesperus* Knight. In the Stern machine, funnels containing three grades of screening were used to partly sort the insects from the debris and forward-facing funnels were used instead of scoops. Stern reported that a total of 80 man-hours was used to collect about 3 million *L. hesperus;* this collection represents a considerable saving over rearing cost.

A machine in which an air blast was used to blow insects into containers was developed for insect control in cotton (5). Although unsatisfactory for this purpose, this machine showed potential for detecting and sampling some insects (5). Kirk and Bottrell (*4*) combined this air blast principle with heated air in a device for sampling low boll weevil populations, *Anthonomus grandis* Boheman, in cotton. The airspeed (up to 135 mi/h) required for these machines makes their use for collecting living insects doubtful.

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[2]Cooperative research of the Agricultural Research Service and Michigan Agricultural Experiment Station, Journal Article 7100.

[3]Italic numbers in parentheses refer to Literature Cited p. 9.

[4]J. R. Maki. A comparison of sampling methods used in field pesticide side effect studies. M.S. Thesis, Mich. State Univ., 34 pp., 1965.

## DESIGN

The present vacuum machine, adapted from the J. A. King vacuum collector, had to actively pick up insects as well as trap them as they flew. The funnel collectors used by Stern and associates (*10*) were not suitable for this purpose. The device also collects cereal leaf beetles close to the ground in stubble or young grain. However, a scoop system, such as that used by van den Bosch and associates (*11*), required clearance to avoid damaging the scoop.

A vacuum head was set as low as possible with high air movement to draw inactive insects into the collector. Preliminary laboratory trials were made of a narrow slit opening on the high vacuum fan described below. For the trials, a piece of plywood containing 50 g of oat seed samples was hand-pushed under a narrow opening while a fan operated at varying speeds. The oat seeds averaged 29 mg (about four times the average weight of a cereal leaf beetle adult reported by Castro and others (*1*)).

The amount of seed the collector drew in increased with fan speeds from 2,255 to 3,720 r/min (fig. 1) and decreased at fan speeds above 3,720 r/min. The fan speed of 3,720 r/min requires an engine speed of 2,750 r/min. This engine speed was used as a standard governor speed. Because the oat seed was not drawn into the collector when placed on a 16-mesh screen, researchers determined that air swirling from the sides as well as from below is needed to lift objects into the collector. The vacuum head design met this need and this principle became the basis for development.

High airspeed at the opening could damage insects. Enlarging the area where the insects were trapped in the net (fig. 2) lowered the airspeed. The airflow was

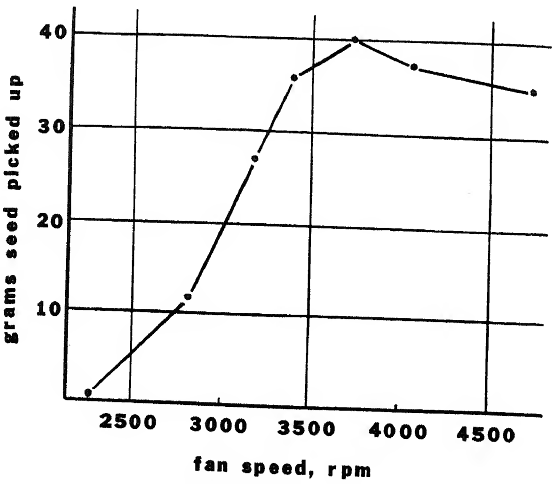


Figure 1.—Grams of oat seed picked up by the vacuum mass collection machine at different fan speeds.

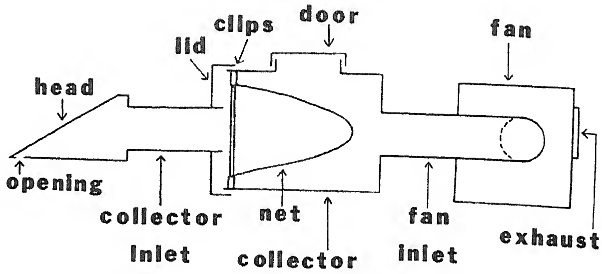


Figure 2.—Diagram of the vacuum mass collection machine.

measured at the opening and at the fan exhaust at different engine speeds. The increment of airspeed at the opening decreased as engine speeds exceeded 2,750 r/min even though air velocities at the fan exhaust continued to increase with greater engine speed (fig. 3). Increased static pressure caused a drop in airspeed at the opening. Estimates of airspeed, based on the air intake at the opening when the engine operates at 2,750 r/min, showed that the insects enter the opening at about 36 m/hr, go through the collector inlet at about 22 m/hr, and are held in the collector by a wind of 10 m/hr.

### Frame and Drive Train

The frame of the device is a 42- by 75-inch rectangle of 3-inch channel iron (fig. 4). Wheel supports placed beneath this frame allow for a 16-inch clearance of the plants; 3.5- by 16-inch motorcycle wheels are used in back and two similar wheels complete with brake assemblies are used in front. The back wheels are mounted in forks of 2-inch channel iron that are attached to a central pivot axle. A steering wheel operates through an automobile steering gear connected to the back wheels. Seat and operator controls are mounted over the drive wheels that have individual foot-operated brakes. To avoid damage to the crop, V-shaped iron rod dividers were placed in front of each wheel. The wheel base was set at 42 inches so the wheels can center between 7-inch grain rows.

A 9-hp, 4-cycle engine mounted with rubber mounts on the frame powers the collector, and two V-belts connect the engine to a hydraulic gear pump-tank combination unit. The pump moves hydraulic fluid through a directional control valve (forward or reverse) and then through a variable flow divider valve (speed control) to either a 9 hp hydraulic orbital motor or back to the supply tank. The return oil from the hydraulic motor passes through a black iron pipe radiator and filter on return to the supply tank. A 3-speed garden tractor transaxle connects the hydraulic motor and a roller

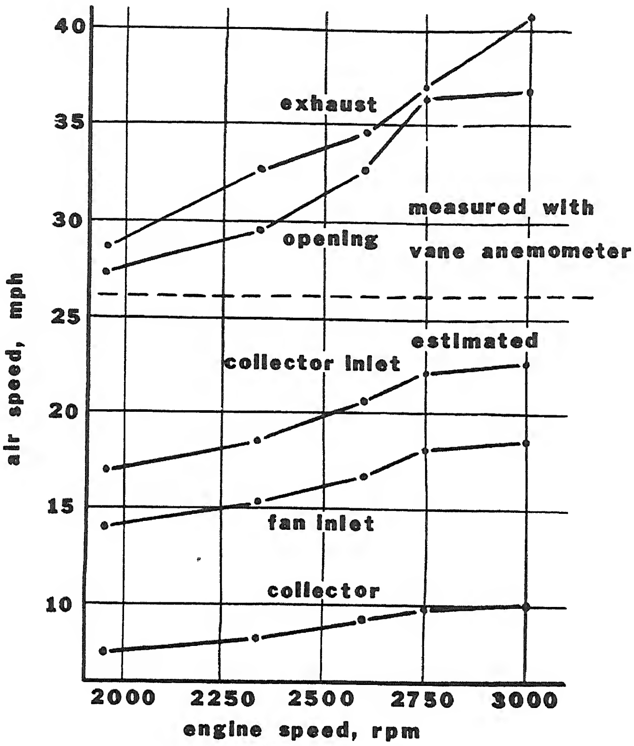

Figure 3.—Air speeds at different points of the mass collection machine operated at different engine speeds.

chain. Drive chains connect the transaxle to the front power wheels.

The forward speed of the device can be controlled by engine speed, the variable flow divider valve, and by the transaxle. The engine also powers the fan and generally operates at 2,750 r/min to provide the necessary power to power train and fan. Standardization of forward speed for the field tests was obtained by fully opening the variable flow divider valve and altering speeds by selection of the transaxle gears. The machine attained speeds of 1.4 mi/h in first gear, 2 mi/h in second gear, and 3.4 mi/h in third gear.

### Fan and Collector

A 12-inch diameter nonoverloading, flat blade, backward inclined blower rated at 2,895 $ft^3$/min at 2,610 r/min with ¼-inch static pressure is the vacuum source (fig. 4). The 9-hp engine powers the blower through double V-belts. The fan speed/engine speed ratio was set by pulleys at 1.35 to permit increased fan speed for greater air movement. A lever-operated idler pulley is the clutch to engage the fan drive. The fan connects to the back of the collector head by a 12-inch diameter furnace pipe and elbows.

The collector is constructed from a 27-gallon galvanized iron garbage can approximately 18 inches in diameter. The increased diameter of the collector over the inlet decreases the airspeed within the collector; less airspeed would reduce the danger of damaging the insects. An 11- by 18-inch electrical box door, fitted into the top of the collector, permits easy access within the collector.

Springs hold the lid of the collector in place, and the collector inlet from the head fits it. The collector inlet is made of 12-inch diameter flexible rubber-canvas hose. Two spring clips and a hook are set in the collector to hold a 15-inch diameter sweep net that is mounted in a standard iron hoop directly in front of the collector inlet. The nets can easily be changed through the electrical box door. Single nylon sweep nets are used, and no attempt is made at rough sorting of debris through multiple nets, as suggested by van den Bosch (11).

The collector head is constructed of ¼-inch plywood reinforced with light gage metal at the edges. The head tapers laterally from the 12-inch collector inlet in back to a 51⅝-inch wide opening in front and tapers vertically from the collector inlet to a 1⅜-inch long opening (this is the final design and gave an opening of approximately 71 $in^2$). The opening is positioned parallel to the ground to facilitate collections in small plants (spring adults of the cereal leaf beetles in young wheat, for example). The head is mounted on parallel arms lifted by a hydraulic cylinder powered from the hydraulic pump through a two-way valve. The opening of the head can be positioned from 1½ inches to 27 inches above the ground.

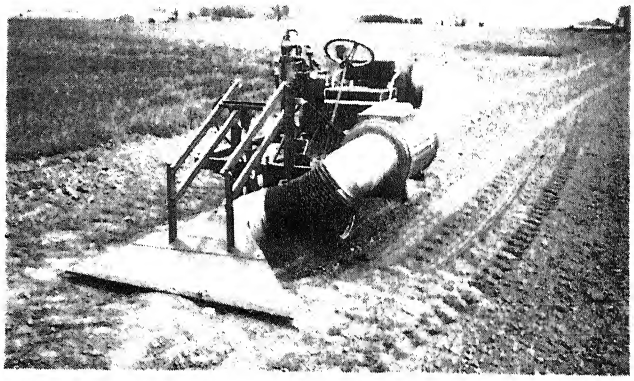
Figure 4.—General view of the vacuum mass collection machine.

## OPERATION

The machine is transported on a small tilting trailer fitted with two automobile transporter loading ramps. One man can operate the machine but two men working the machine is more convenient—one man drives the machine and the other man tends the nets and cages.

The machine was used during the 1973 and 1974 seasons to collect large numbers of cereal leaf beetle adults and larvae, alfalfa weevil adults, and tarnished plant bug adults. For these collections the method was to (a) adjust the engine speed and head height, (b) place an empty net in the collector, (c) run a long swath (up to one mile in length) with the device, (d) empty the contents of the net into bags or cages of a 16-inch cube covered with 32-mesh screen, (e) transport the bags or cages to the laboratory either for immediate sorting or for storage at 38°F, and (f) sort out the desired insects using aspirators operated from a vacuum pump.

During both seasons the machine's operation proved generally satisfactory. It ran with a minimum of maintenance and without field breakdowns. The machine can be operated comfortably at speeds up to 3.4 mi/h on level ground, 2 mi/h on fairly even ground (such as a cultivated field), and at 1.4 mi/h on rougher lands (such as weed borders or old meadows).

Emptying the net and replacing it with an empty one took from 1 to 2 minutes. The insects, even such fragile ones as the lacewing, *Chrysopa oculata* Say, usually appeared undamaged after collection by the machine. Survival was good of the cereal leaf beetle and alfalfa weevil adults collected by the machine. When collecting in wet vegetation, the air moving through the net removed much of the water picked up. Little damage was evident from moisture breaking the wings or sticking insects to the net such as occurs with the sweep net. The machine caused little damage to the crop—the dividers in front of the wheels reduced tearing of the leaves, and the wheel marks were light and transitory even in heavy vegetations.

## COSTS

The machine was made of materials on hand and salvage materials as well as new or used materials that were specially purchased. The machine also went through several major modifications during development. Cost of materials that were actually used for its construction cannot, therefore, be accurately determined. The prices listed in table 1 are either the actual price paid for materials purchased specifically for the machine or are list prices for the materials current at the time of construction. The machine was entirely made in a shop containing hand tools, welding equipment, and some common power tools; no precision machinery or specialized equipment was needed. The work was done principally by the senior author; labor costs are not included.

Table 1.—*Estimated costs for construction of a vacuum mass insect collecting machine*

| Item | Cost |
|---|---|
| Hydraulic motor | $ 86 |
| Gasoline engine | 163 |
| Pump-reservoir unit | 110 |
| Wheel assemblies (4) | 100 |
| Transaxle (1) | 15 |
| Hydraulic hose | 30 |
| Sprockets and chain | 40 |
| Control valve | 30 |
| Flow divider valve | 45 |
| Seat | 10 |
| Furnace pipe | 20 |
| Plywood | 20 |
| Iron and pipe | 100 |
| Fan | 158 |
| Steering gear | |

The best cost estimate of operating the machine is a maximum of $0.20 per acre. Workday with the machine is about 6 to 7 hrs of an 8-h day. At a speed of 2 mi/h (second gear at 2,750 r/mi engine speed) the machine will collect about 6.26 acres in a 6-h workday. Allowing a salary of $2.70 an hour, the collecting cost is about $3.65 per acre with the machine. The best estimate for collecting with sweep nets is that one man collects about 0.61 acre per hour with a 3- to 4-h workday. One man with a sweep net can collect from 2.44 acres per workday at the $2.70 an h salary—this collecting cost is $8.85 per acre.

If two men were needed to operate the machine, the difference in operating costs between the machine and the sweep net would be small, and depreciation of the machine would probably eliminate the difference completely. The machine will collect more insects per area (an average of threefold increase) than the sweep net, which is an important consideration where collecting time is limited.

e cost per insect collected by the machine could

be less than one-third that of the sweep net even when two men are used to operate the machine. The machine can also be used in stubble and seedling grains, under weather conditions that would limit sweep nets, and longer per day than the sweep net because of its reduced operator fatigue.

## FIELD TRIALS

Van den Bosch and associates (*11*) and Stern and associates (*10*) listed the insects collected with their vacuum devices, but quantitation of the effectiveness of their devices against different types of insects was not cited. However, Maki[3] found the portable vacuum collecting device he used was selective in its sampling of different insect species. The number and species of insects collected by the present vacuum device were compared with insects taken with the sweep net. A range of insects was obtained by testing the device in alfalfa—a crop wih a diverse insect fauna. The tests were made in early- and mid-season and in stubble and heavy growth to find how the machine would operate under diverse conditions.

### Preliminary Field Testing

A preliminary field test of the machine was made May 1[illegible], 1973, in a new stand of vigorous but weedy alfalfa near Mason, Mich. The alfalfa was about 15 inches tall; tested between 2 and 4 p.m.; air temperature 57° F; wind at 10 mi/h with gusts to 20 mi/h; partly cloudy with a brief period of hail and rain; soil moist; and plants wet from rain.

The machine was first tried by taking several long swaths at 1.4 mi/h, 2,750 r/mi engine speed and with the head in the upper part of the alfalfa. The more abundant insects collected, as noted by examination in the field, were alfalfa weevil adults and a few grubs; ladybeetles; syrphid flies; *Nabis* sp.; tarnished plant bug adults; spiders; leafhoppers; *Chrysopa* sp.; cereal leaf beetle adults; braconids (all parasitic *Hymenoptera*); pea aphid, *Acyrthosiphon pisum* (Harris); honey bees, *Apis mellifera* L.; flies; gnats; and weevils other than the alfalfa weevil.

Sweep net collections made at the same time showed the same range of insects as the collector. The sweep net collections were wet and the insects were stuck together with moisture. The insects in the collector were clean and dry and seemed to be in generally good condition. The machine was then tested at 2 mph with the head near the upper part and about 4 to 5 inches deep in the alfalfa. The increase in speed and depth increase in the alfalfa seemed to increase the number of insects collected. A test was attempted with the machine operated at 3.4 mi/h, but the field was rough and the higher speed was too fast for easy handling of the machine.

The machine proved to be easily adjusted for head height and speed and only a few minor problems with its operation were found in these trials. A 400-foot long swath was made with the machine after the mechanical adjustments had been made. The machine operated satisfactorily in this test and a large mass of insects was collected.

Cool, wet weather at the time of these trials made net sweeping difficult and unpleasant for the collector and yielded wet, damaged specimens. Mass collection by sweep nets would not have been attempted under the test conditions. The machine yielded specimens in excellent condition without undue operator fatigue. Apparently, the machine can be used under conditions that would limit mass collection with sweep nets.

### Test of May 17, 1973

Four pairs of plots were laid out in the field and conditions noted as in the preliminary field testing. Twenty sweeps with a sweep net were made in one plot of each pair and the other plot was collected using the machine operated at 2 mi/h, 2,750 r/mi engine speed, and the head about 4 inches deep in the alfalfa. The collections were processed and counted as outlined by Ruppel (*7*).

Seven taxa (table 2) were found in sufficient numbers to yield reliable information. The data for "other weevils" and pea aphids were analyzed using a Chi$^2$ test for heterogeneity. The numbers of the other insects were too low for this test, and the data of the four replications of each treatment were analyzed using the pooled Chi$^2$ test with the adjustment for small collection sizes.

The machine gave significantly higher numbers of the different insects than the net (table 2). With the exception of the "other weevils" (a complex of species from the weeds in this field), however, the number of insects collected was too low to put too much confidence in the results. Also, the weather was unsuitable for net sweeping. This test was encouraging as it indicated that the machine would collect such varied insects as pea aphids (small, slow moving) and tarnished plant bug adults (medium-sized, active) at least as well as the sweep net.

### Test of July 11, 1973

A test comparing the collector with the sweep net was made near Hickory Corners, Mich., from 7 to 9 p.m.

Table 2.—*Mean number of insects collected with a sweep net and a vacuum collector, May 17, 1973*

| Insect | Collecting method | Mean number per sample | Ratio (collector: net) |
|---|---|---|---|
| Other weevils, | Net | 37.75 | |
| adults[1] | Collector | [2]122.75 | 3.25 |
| Alfalfa weevil, | Net | 2.00 | |
| adults | Collector | [2]6.75 | 3.38 |
| Tarnished plant bug, | Net | 1.75 | |
| adults | Collector | [2]6.00 | 3.43 |
| Nabids, adults | Net | 1.75 | |
| | Collector | [2]9.00 | 5.14 |
| Pea aphid, | Net | 1.75 | |
| all stages | Collector | [2]9.25 | 5.29 |
| Ladybeetle, adults | Net | 0.75 | |
| | Collector | [2]5.25 | 7.00 |
| Spiders, | Net | 0.50 | |
| all stages | Collector | [2]4.25 | 8.50 |

[1]Weevils other than the alfalfa weevil.
[2]Highly significant difference between means.

on July 11, 1973. The alfalfa stand was good, but it decreased in vigor and increased in weediness toward the center of the field. The alfalfa was about 22 inches tall near the edge and about 15 inches tall near the center. The air temperature was 70° F; sky clear; plants and soil dry; and wind calm. The experimental design and analysis were the same as described above for the test of May 7, 1973. The machine was operated at 2 mi/h, 2,750 r/mi engine speed, and with the head positioned about 14 inches above the soil.

The head of the collector did not enter the shorter alfalfa in the fourth replication in this test; therefore, it was dropped from the analysis. Some means of adjusting head height while operating the collector was needed; a hydraulic cylinder adjustable by the operator was subsequently added to the collector.

Eleven insect taxa were collected in sufficient numbers to give reliable information (table 3). With the exception of the meadow spittlebug adults, *Philaenus spumarius* (L.); grasshopper nymphs, *Melanoplus* spp. and other leafhoppers (the last had low numbers), the collections obtained with the collector were significantly larger than those obtained with the net. The differences range from nearly equal (the grasshopper nymphs) to a 8.71-fold increase with the collector (lepidopterous larvae). The mean increase in all taxa was 3.29 more insects collected by the machine than with the sweep net.

A Chi$^2$ test of homogeneity showed that the proportion of insects taken with the machine or with the net differed significantly with the different taxa. The mean increase of 3.29 is useful only as a crude efficiency index. The insects that showed the lowest increase in numbers collected with the machine (tarnished plant bug adults, meadow spittlebug adults, and grasshopper nymphs) are medium to large-sized, active insects. Conversely, the machine was more efficient with two different insects; the small, active potato leafhopper adults, *Empoasca fabae* (Harris), and the large, slow lepidopterous larvae. Apparently the machine may be limited in effectiveness with the faster moving, stronger insects.

A number of other taxa were taken in small numbers in this test; all taxa were taken with both the machine and the net. The weather and time of day was excellent for collecting with a sweep net in alfalfa during this test (7). It showed that the machine collects the same range of insects as the sweep net and, with some exceptions, the machine will obtain appreciably larger number of insects from an equal area than will the sweep net.

### Test of July 3, 1973

A comparison of the sweep net with the machine operating at different speeds was made near Mason, Mich., on July 3, 1973. A second year stand of moderately vigorous alfalfa with few weeds was used in the test. The first cutting had been made before the test, and

Table 3—*Mean numbers of insects collected with a sweep net and a vacuum collector, July 11, 1973*

| Insect | Collecting method | Mean number per sample | Ratio (collector: net) |
|---|---|---|---|
| Grasshopper | Net | 21.67 | |
| nymphs | Collector | [1]20.00 | 0.92 |
| Meadow spittlebug, | Net | 20.33 | |
| adults | Collector | [1]26.33 | 1.30 |
| Tarnished plant bug, | Net | 55.67 | |
| adults | Collector | [2]102.33 | 1.84 |
| Other leafhoppers, | Net | 4.00 | |
| all stages[3] | Collector | [1]8.33 | 2.08 |
| Other mirids, | Net | 3.67 | |
| all stages[4] | Collector | [5]8.00 | 2.18 |
| Nabids | Net | 8.33 | |
| | Collector | [2]20.00 | 2.40 |
| Pea aphids, | Net | 4.33 | |
| all stages | Collector | [2]11.00 | 2.54 |
| Alfalfa weevil, | Net | 23.00 | |
| adults | Collector | [2]83.67 | 3.64 |
| Alfalfa weevil, | Net | 96.33 | |
| grubs | Collector | [2]368.67 | 3.83 |
| Potato leafhopper, | Net | 32.00 | |
| adults | Collector | [2]217.33 | 6.79 |
| Lepidopterous | Net | 2.33 | |
| larvae | Collector | [2]20.33 | 8.71 |

[1]Not significant.
[2]Significant at the 1 percent level.
[3]Leafhoppers other than the potato leafhopper.
[4]Mirids other than the tarnished plant bug.
[5]Significant at the 5 percent level.

the regrowth was about 6 inches tall when collected. The air temperature was 70° L, wind slight, sky hazy-bright, soil wet, and plants dry.

Plots 50 ft long by 10 ft wide were arranged in randomized block design with four replications. Collections of 20 sweeps with a 15-inch diameter insect net were made in one plot of each replication and were taken with the machine operating in first gear or second gear in the other plots. The collector head was placed about 1 inch deep in the alfalfa with the machine operating at 2,750 r/mi. The collections were sorted and counted as described above, and the data were analyzed using an analysis of variance.

No significant differences were analyzed between the means of the collections obtained using the net or the machine operating at either speed with the tarnished plant bug adults, all stages of nabids, Nabis sp., other weevil adults, and flies (table 4). The machine, operated at either speed, gave significantly larger collections of alfalfa weevil adults and grubs than did the sweep net. In first gear, the machine collected larger numbers of grasshopper nymphs and significantly smaller collections of meadow spittle bug adults, and in second gear significantly larger collections of pea aphids than in the other treatments. The mean number of potato leafhopper adults increased significantly with each change from the sweep net, to first gear, to second gear.

This test showed that the machine is effective in stubble as well as in the taller plants used in the prior test. The same insects that proved difficult to collect with the machine in the July 11 test also proved difficult in this test. Decreasing the forward speed of the machine increased the number of grasshopper nymphs but decreased the number of meadow spittle bug adults. The faster moving spittle bugs probably escaped the slow-moving machine whereas more of the slower, bulkier grasshopper nymphs were probably drawn in at the slower speed. The machine worked well at collecting adults and grubs of the alfalfa weevil, and at its faster forward speed, the pea aphid, and was excellent for collecting potato leafhopper adults.

### Test of July 19, 1973

A test to determine the interaction of the speed of the machine and depth of the collector head in the crop on different insect collections was made near Mason, Mich., on July 19, 1973. The alfalfa field was the same one as the test July 3, but the alfalfa had grown to about 15 inches tall. The temperature was 85° F, winds moderate, hazy to overcast sky, soil surface dry, and plants dry. The plots, 10 ft wide by 50 ft long, were arranged in randomized blocks with four replications.

Table 4.—*Mean number of insects collected with a sweep net and with a vacuum collector operated at different speeds, July 3, 1973.*

| | Mean number per sample[1] | | |
|---|---|---|---|
| Insect | Net | 1st gear | 2d gear |
| Tarnished plant bug, adults | 4.50a | 5.50a | 2.00a |
| Nabids, all stages | 13.00a | 17.75a | 22.25a |
| Other weevils, adults[2] | 4.25a | 7.50a | 12.50a |
| Flies | 13.25a | 17.75a | 16.25a |
| Meadow spittlebug, adults | 22.25b | 11.25a | 20.50b |
| Grasshoppers, nymphs | .75a | 17.25b | 1.75a |
| Pea aphid, all stages | 90.50a | 59.00a | 136.50b |
| Alfalfa weevil, grubs | 7.50a | 34.50b | 31.25b |
| Alfalfa weevil, adults | 2.75a | 15.00b | 14.00b |
| Potato leafhopper, adults | 2.75a | 18.25b | 50.50c |

[1]Means in the same row followed by the same letter are not statistically significant at the 5 percent level by the Duncan New Multiple Range Test.

[2]Weevils other than the alfalfa weevil.

The machine was operated in combinations of first, second, and third gear with the collector head about 4 inches and 8 inches deep into the alfalfa. Twenty sweep net collections were also taken as one of the treatments. As noted above, the collections were sorted and counted. Variance analyses were made for all treatments and for main plot (speed and depth) interaction for machine speed and head depth combinations.

Treatments with the head 12 inches deep in the alfalfa had been planned for this test. The first collections taken, however, picked up too large a volume of trash (mostly dropped leaves) to process, and the 12-inch treatment was dropped from the the test. The results show that the insects (tarnished plant bug adults and nymphs, other mirids, nabids, and meadow spittle bug adults) gave no significant differences between their means in this test (table 5). In addition, there were no significant differences in the numbers of pea aphids nor lepidopterous larvae between treatments in this test. The coefficient of variation for both insects were high (33 percent and 38 percent, respectively), and not much confidence can be placed in these results.

All treatments with the machine were significantly better for grasshopper nymphs than with the sweep net. There were minor significant differences between individual treatments with the machine. The major difference in the main plots, however, was the reduced collection obtained in third gear. There were no significant differences in head depth main plots nor in interaction between main plots with the grasshopper nymphs.

The machine treatments were significantly better than the sweep net for alfalfa weevil adults. No significant

Table 5.—*Mean number of insects collected with a sweep net and with a vacuum collector operated at different speeds and different depths, July 19, 1973*

| Insect | Net | 1st gear 1.4 mi/h | | 2d gear 2 mi/h | | 3d gear 3.4 mi/h | |
|---|---|---|---|---|---|---|---|
| | | 8 inches | 4 inches | 8 inches | 4 inches | 8 inches | 4 inches |
| | Mean Number per sample[1] | | | | | | |
| Tarnished plant bug, nymphs | 1.25 | 1.75 | 5.00 | 4.50 | 5.75 | 3.25 | 3.50 |
| Tarnished plant bug, adults | 37.25 | 35.25 | 29.50 | 20.00 | 28.25 | 32.50 | 28.50 |
| Other mirids[2] | 5.25 | 3.00 | 7.50 | 3.50 | 4.25 | 1.50 | 3.25 |
| Nabids | 11.75 | 9.00 | 18.25 | 12.00 | 15.50 | 12.00 | 12.25 |
| Meadow spittle bug, adults | 19.25 | 13.75 | 20.25 | 19.25 | 13.00 | 21.25 | 18.75 |
| Pea aphid | 13.50 | 5.25 | 9.25 | 13.00 | 10.25 | 8.00 | 8.00 |
| Lepidopterous larvae | .75 | 2.50 | 6.75 | 8.50 | 3.25 | 3.75 | 2.75 |
| Grasshopper nymphs | 1.00a | 4.00c | 3.00bc | 3.25bc | 4.75c | 2.25b | 1.50b |
| Alfalfa weevil, adults | 1.50a | 8.50b | 9.50b | 6.00b | 8.23b | 5.00b | 8.75b |
| Alfalfa weevil, grubs | 1.75a | 2.75ab | 4.75b | 8.50c | 4.00ab | 4.50b | 2.25 |
| Potato leafhopper, adults | .50a | 210.75d | 115.00bcd | 184.75cd | 58.50b | 93.50bc | 66.00b |
| Potato leafhopper, nymphs | .25a | 34.00e | 7.50bc | 28.50de | 5.50bc | 11.25bcd | 3.75b |

[1]Means in the same row followed by the same letter are not statistically significant at the 5 percent level by the Duncan New Multiple Range Test.

[2]Mirids other than the tarnished plant bug.

differences occurred between the means of alfalfa weevil adults in the individual treatments nor main plots with the machine; there were significant differences in the means of the numbers of alfalfa weevil grubs collected in the individual treatments. The faster speed gave fewer grubs than the two slower speeds, and the 2 mi/h speed was significantly better than 1.4 mi/h speed. The 8-inch collection depth in the alfalfa gave more grubs than did the shallower 4-inch depth. There was a highly significant interaction between main plots with the combination of 2 mi/h with the 8-inch collecting depth being highly effective with the grubs.

As in the prior July 3 test, the machine proved highly effective in collecting potato leafhopper adults and also the nymphs in this test. Significantly more adults and nymphs were collected at the 8-inch than at the 4-inch collection depth. The speed had no effect on the number of adults collected, but the slower speeds gave more nymphal leafhoppers than the highest speed. There were no significant interactions between speed and depth of collections with respect to either stage of leafhopper in this test. All samples collected by the machine were significantly greater than those by sweep net. There were also significant differences in the means of both stages of the leafhopper collected in the individual treatments with those taken at the 8-inch depth at the slower speeds being especially high.

## DISCUSSION

Although specifically designed for the collection of the cereal leaf beetle adults, the machine will collect as wide a range of species as the sweep net. The increase in effectiveness of the machine over the sweep net varies with the species.

The machine was excellent for collecting potato leafhopper adults and nymphs and alfalfa weevil adults and grubs, as well as lepidopterous larvae, pea aphids, mirids other than tarnished plant bug, and leafhoppers other than the potato leafhopper. These species represent a wide diversity from the small, active potato leafhopper to the large, slow, lepidopterous larvae. The effectiveness of the machine with the potato leafhopper was outstanding and, considering its design, was unexpected. Apparently, the leafhoppers are light enough to be sucked into the collector head while in flight.

The machine was poorest with the tarnished plant bug adult, meadow spittlebug adults, nabids, and grasshopper nymphs. These are medium to large, active insects that were able to avoid the collector head. The use of wide funnel nets (*10*) would probably be more effective with such insects than the narrow opening used on this machine. Although the machine was not as effective as with other species, it did satisfactorily collect large numbers of tarnished plant bugs for testing.

The present machine could be altered to use a funnel-shaped net by replacing the head with a tube connected to a net by large diameter furnace pipe. A scoop type head of the type (*11*) could be adapted to the present device by simply fastening a properly formed sheet metal piece under the present opening on the head. The trash picked up by the machine in the July 19 test points

up a problem that could be reduced by using a coarse net to catch the trash as done by van den Bosch and associates (*11*).

The last two tests show that the results of some species, such as grasshopper nymphs, can be improved somewhat by adjusting the speed or depth of collection of the collector head. Ignoring the importance of the specificity of the machine (and, especially, huge differences of potato leafhopper between it and the sweep net), the overall ratio of insects collected by the machine over the sweep net is 3.77-fold. This represents a reduction in collection cost per insect over the use of the sweep net.

The tests show that the machine can be used in various crops and weather conditions. The cold, wet weather of the May 17 test would have discouraged sweep net collecting and may have resulted in many specimens being damaged by moisture in the nets. The machine performed well under these conditions as well as collecting in both the short stubble on July 3 and the heavy growth of July 19.

Ruesink,[5] Maki,[4] and Ruppel (7) have shown how weather, time of day and other factors influence sampling of insects. Knowledge of how such factors influence the collections of a specific insect could be used to increase the efficiency of its collection. The objective of the present test was to compare the effectiveness of the machine with that of the sweep net. The results with specific insects reported here were influenced by these factors, of course, and could be quite different under other circumstances.

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